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HILLMAN,
T.W.

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TESTING SEDIMENT-FISH RESPONSE COEFFICIENTS AND MODELS: EFFECTS OF SEDIMENT ON SURVIVAL OF CHINOOK SALMON DURING THE FIRST YEAR OF LIFE

FINAL REPORT TO
INTERMOUNTAIN FOREST AND RANGE EXPERIMENT STATION
OGDEN, UTAH
ADODR: W.S. PLATTS

TRACY W. HILLMAN

J. S. GRIFFITH

DEPARTMENT OF BIOLOGICAL SCIENCES
IDAHO STATE UNIVERSITY
POCATELLO, IDAHO 83209

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INTRODUCTION

The work carried out in 1985 was centered around identifying habitats utilized by juvenile chinook salmon (Oncorhynchus tshawytscha) during summer and winter rearing. Two sites were altered by the addition of cobble so the effects of sediment on winter habitat utilization could be evaluated. We also identified habitats selected for spawning and began the initial process of determining egg to alevin survival. The specific objectives of the work outlined here were:

a. to assess the densities and biomass of juvenile chinook salmon utilizing study sections of the Red River system during summer and winter,

b. to identify the habitats selected by juvenile chinook salmon for summer and winter rearing,

c. to evaluate the possible relationships between sediment levels and summer and winter habitat utilization,

d. to identify spawning sites selected by chinook salmon, and

e. to determine the extent to which sediment particle size is modified during redd construction by female chinook salmon.

STUDY AREA

Red River is a tributary of the South Fork Clearwater River draining an area of approximately 36,761 hectares (Figure 1). The drainage lies within the Idaho batholith border zone and is predominated by moderately sloping basin lands and terraces. Extensive floodplains occur along tributary streams, and are mainly under private ownership. These areas now are primarily pasture and natural meadows.

Flows between July and November on the Red River (measured above the Red River Corrals) ranged between 0.2 m^3/s in mid-August to 0.8 m^3/s in late September. Water temperatures ranged from 19 to 0.5 C from July through November.

Fish species present in the study area (in order of decreasing abundance) in 1985 included: juvenile chinook salmon, juvenile steelhead trout (Salmo gairdneri), mountain whitefish (Prosopium williamsoni), catchable-sized rainbow trout, bull trout (Salvelinus confluentus), brook trout (Salvelinus fontinalis), and cutthroat trout (Salmo clarki). Bridgelip sucker (Catostomus columbianus), longnose dace (Rhinichthys cataractae), speckled dace (Rhinichthys osculus), and sculpin (Cottus sp.) were found but their abundance was not assessed. In 1984, age 0 chinook salmon made up 90, 95, and 88% of the numbers of salmonids collected in July-August, September, and November, respectively.

A total of nine sampling stations were selected which contained a spectrum of physical habitats. Five sites are located on the upper Red River (referred to as the North Fork Red River throughout the text) upstream from the confluence of the South Fork Red River. The lower site begins immediately below the newly constructed sediment trap, below the developed campgrounds on Forest Service Road #234. The third and fourth sites begin approximately 100 m upstream from the first bridge above the Red River Corrals. The fourth and fifth sites begin approximately 250 m downstream from the next road bridge, with Bridge Creek entering immediately upstream from the upper site.

The two sites originally established on the South Fork, beginning below the confluence of Deer Creek and extending upstream past a culvert passing under the highway, were excluded from intensive study in 1985 because 1985 sampling indicated no age 0 chinook salmon were present in

these areas. We therefore established two sites beginning approximately 350 m upstream from the mouth of the South Fork and extending upstream past two K-dam structures. The final two sites were located on the lower Red River along the Forest Service stock pasture, immediately below the chinook rearing ponds.

With the exception of the Bridge Creek and Sediment Trap sites on the North Fork and the South Fork sites, all sites were those established and sampled by Intermountain Station personnel for FISHSED studies.

METHODS

Chinook Density and Biomass

Densities and biomass of juvenile chinook salmon were calculated within the 100 m study sites established by the Intermountain Station personnel. In August we placed a 5-mm-mesh seine at the upper and lower ends of each study site and electrofished the site, working upstream with backpack shockers. Using the same equipment and personnel on each pass, we made four complete passes. We maintained fish from each pass in separate holding tanks.

After measuring, weighing, and counting fish from each pass, juvenile chinook population sizes were calculated with the maximum-likelihood formula (Platts et al. 1983). Once populations had been estimated, we used weights to calculate biomass in terms of grams of fish tissue per square meter.

Sampling in October was identical to that conducted in August except without the aid of the Intermountain Station personnel. In November blocking seines were not needed because cold temperatures precluded fish movement out of the sites.

Juvenile Rearing Habitat

Focal points of juvenile chinook were quantified by divers using dry

suits and snorkels and noted on habitat maps. Densities were assessed by using a multiple-pass electroshocking method and chinook were marked by fin mutilation in October to evaluate movement out of the sites. To relate stream sediment with winter habitat utilization by chinook salmon, the streambed of a riffle and glide was altered by the addition of granitic cobble. Chinook densities were assessed before and after alteration.

All study sections were mapped to scale, using the plane table-alidade method, by habitat class, using the habitat class rating criteria in Appendix 1. Fish were located and noted on the habitat maps from July through November by divers using dry suits and snorkels. Habitat utilization observations were made the third week of each month.

Microhabitat analysis was made concurrently with habitat observations during the months of July through November. Undisturbed age 0 chinook salmon were observed by one diver snorkeling in an upstream direction. The diver entered the water at least 15 m downstream of the site and slowly crawled along the bottom of the stream looking for undisturbed chinook salmon. When the diver sighted a fish he observed it from downstream until he could accurately estimate its focal point. If a fish showed any indication of alarm or displacement, microhabitat analysis was not initiated.

For each juvenile chinook salmon observed, the following microhabitat measurements were recorded: (1) total depth of the water column, (2) focal point elevation (the distance between the snout of the fish and the substrate) (3) focal point velocity, (4) distance to nearest cover, (5) type of instream cover selected, (6) distance from other fish, and (7) substrate composition. We measured overhanging terrestrial vegetation on the first few study sections but later decided that it did not provide

cover for chinook salmon and discontinued these measurements. A third depth variable, relative depth, was calculated by subtracting focal point elevation from total depth and then dividing by total depth. Velocity measurements were made with a Marsh-McBirney Model 201 electromagnetic flow meter with all values converted into centimeters/second. The substrate composition was visually estimated in an area of 0.25 m^2 directly beneath the salmon. Percent substrate composition was based on a modified particle size scale (in Platts et al. 1983) in which codes ranged from 1 for plant detritus to 8 for bedrock (Bovee and Cochnauer 1977, Appendix 2). A single numeric score for adjacent substrate codes was generated by weighting the percentages of the two dominant substrates (Moyle and Baltz 1985). Thus, a section containing 10% sand (code 4), 60% gravel (code 5) and 30% cobble (code 6) would be coded 5.3 indicating a dominance of gravel and a lesser proportion (0.3) of the adjacent larger class.

To determine the movement of age 0 chinook from summer rearing habitats into winter rearing habitats, a number of chinook were marked in three different reaches of the North Fork. The upper-most reach was located immediately below Bridge Creek with the second reach located approximately 300 m upstream from the first bridge above the Red River Corrals. The third reach was located immediately below the sediment trap. Each reach, approximately 5 km apart, was divided into three marking sites with juvenile chinook receiving a different fin clip in each site. A small side channel located along the sediment trap was also used as a marking site. Thus, a total of ten different fin clips corresponded to the ten marking sites.

Fish were collected on 10-18 October by using a three-pass electroshocking method and marked. On 4-15 November, the three reaches plus

300 m of stream above and below the reaches were electroshocked to relocate marked fish.

Stream Bed Alteration

To evaluate the possible relationships between sediment and winter habitat selection of juvenile chinook salmon, two sites located below Bridge Creek were selected. The upper site is a homogenous riffle habitat approximately 23 m in length and the lower site a homogenous glide habitat 31 m in length (Table 1). In September, the riffle had an estimated embeddedness rating (from Platts et al. 1983) of 2 while the glide had an estimated rating of 1.

On 24 September the sites were altered by the addition of granitic cobble (mean maximum diameter of cobble, 19 cm; range from 9 cm to 37 cm). Each site was altered with cobble, piled 26 cm deep, in both the exposed benthic area and the benthic area under the banks. The exposed benthic area is the difference between total benthic area and benthic area under banks. Four percent of the exposed benthic area was altered with cobble placed in nine 1 m^2 plots located in center stream while approximately 30% of the benthic area under the banks was altered.

Fish population estimates were made on 4 April by using a three-pass electroshocking method and 21 September by using dry suits and snorkels. After addition of cobble, population estimates were made on 10 October and 8 November by a three-pass electroshocking method.

Spawning Habitat

Accessible sections of the Red River were walked during the period of 21-27 August to locate chinook salmon redds. For each active redd located, the following habitat measurements were recorded: (1) water depth over the redd, (2) water velocity over the redd, (3) area of the redd, (4) distance to nearest cover, (5) substrate composition, and (6) embeddedness rating.

Water column depths and velocities were taken at the upstream edge of the redd. Redd area was computed by measuring the total length of the redd and the mean of several equidistant widths. The substrate composition was visually estimated in an area directly adjacent to the redd. The process of coding percent substrate composition is identical to that used in microhabitat analysis. Embeddedness rating (Platts et al. 1983) was visually estimated.

To determine spawning area sediment conditions and changes in the sediment from substrate cleansing by the spawning female salmon, sediment cores were lifted using a McNeil-Ahnell hollow-core sampler. Cores were lifted on 6-13 August and 19-21 September indicating periods of pre-spawning and immediately following spawning, respectively. Cores will be lifted again on 17-21 March to determine redd pocket conditions during emergence of the salmon alevins.

Core sediments were separated using U.S. standard sieve sizes of 75.6, 25.4, 9.5, 6.3, 0.85 and 0.212 mm. All rocks over 75.6 mm in diameter were measured and weighed individually. The quantity of suspended sediment was determined by using Imhoff (settling) cones. The geometric mean (dg) and sorting coefficient (So) were calculated for each gravel sample from its sieved fractions and the Fredle index (f) was calculated by taking the quotient of dg/So (Lotspeich and Everest 1981). Survival from egg to alevin was calculated using the equation for chinook survival derived by Tappel and Bjornn (1983).

RESULTS AND DISCUSSION

Chinook Density and Biomass

Chinook densities in August 1985 in the upper portion of the North Fork exceeded 75 fish per 100 m^2 of stream surface (Table 2). Summer densities

were over eight times that found in November sampling. Summer densities in 1985 were 40% greater than densities in 1984 but densities in November 1985 were 40% less than those in 1984. With a decrease in density a decrease in biomass from 0.8 g/m^2 in August to 0.3 g/m^2 in November was observed (Table 2).

Growth was fairly rapid up through October. Then, with stream temperatures dropping below 2 C, growth nearly stopped (Figure 2).

Juvenile Rearing Habitat

With a decrease in temperature, a change occurred in habitats selected by juvenile chinook salmon. When temperatures were greater than 2 C (July through October) most age 0 chinook were concentrated in lateral scour pool and glide habitats (Figure 3). The highest densities were along the fringes of pools (glides) focused along the lateral and tail ends of the pools. Few juvenile chinook were utilizing the anterior fringes of the pools. Less than 5% of those present were utilizing riffle habitats. The few salmon that were located in riffles were usually found behind small boulders where water velocities were lower. From July through September no juvenile chinook were observed utilizing pools where other species of catchable-sized salmonids were located.

The use of depth, velocity and substrate by age 0 chinook was fairly consistent from July through September (Table 3, Figures 4-6, & 8). As fish size increased, movement to increased depth and velocity was noted. In July the salmon were utilizing a mean water depth of 44 cm which increased to 49 cm in September (Table 3). Mean focal point velocity increased from 10 to 13 cm/s from July to September, and focal point elevation also increased (Figures 5 & 6). During this period the chinook were predominantly found over a sand-gravel (0.83 to 76.0 mm) substrate (Figure 8).

Most chinook were concentrated in clusters of one to several dozen

individuals and when agitated moved to undercut banks for cover. Chinook utilizing riffles were distributed individually and when frightened moved a short distance and then returned to their station almost immediately.

A trend in spatial distribution is indicated by the increased distance from cover observed from July through September (Table 3, Figure 7). In July the fish were located a mean distance of 88 cm from cover (undercut banks). This increased to 172 cm in September, indicating lateral movement from the bank with an increase in fish size.

A transition in habitat utilization from summer rearing to winter rearing occurred in October when stream temperatures dropped to 4 C. Most chinook were still located in lateral scour pool and glide habitats (Figure 3) but were selecting a wider spectrum of microhabitats (Table 3, Figures 4-6, & 8). A wide range of depths (14 to 107 cm) were being utilized at this time (Figure 4) with chinook located both at the water surface and the stream bottom (Figure 5). Where water depths were greater than 70 cm, chinook were consistently located very near the stream surface. The pools with water depths greater than 70 cm usually had catchable-sized trout stationed near the substrate. Juvenile chinook consistently maintained a distance greater than 50 cm above these fish. No chinook were utilizing riffle habitats. Thus, with the increased utilization of pools by dense clusters of chinook, reaching 250 individuals per group, it is assumed that the fish utilizing riffles during summer rearing moved to the pool habitat with the decreased temperature. Fish distributed in these large groups displayed little reaction when frightened, often moving a short distance and then returning to their station almost immediately. Water velocities were fairly consistent, ranging between 4 to 23 cm/s (Figure 6). The salmon were predominantly found over a sand-gravel (0.83 to 76.1 mm) substrate (Figure 8).

In the November sampling, water temperatures had dropped below 2 C and anchor, frazil, and shelf ice had formed in most locations. The chinook selected lateral scour pools (undercut banks) and secondary channel riffle habitats (Figure 3). As in 1984, the highest densities of juvenile chinook were located along undercut banks and in side channels where dense growths of sedge (Carex sp.) were draped over the bank and extended under the water surface. Fish stationed themselves in this dense Carex using it to keep their bodies upright although occasionally chinook were observed laying on their sides. Fish were individually distributed with no clusters of chinook found in this habitat. Bare undercut banks with no vegetation present were not used. Chinook not utilizing undercut banks were found utilizing interstitial spaces in the substrate in riffle habitats.

Juvenile chinook using undercut banks were predominantly found close to the surface of the stream (Figure 5) with focal point velocities less than 12 cm/s (Figure 6). If the water velocity was greater than 12 cm/s, no chinook were found even if Carex was extending below the surface of the water. Chinook were found in water depths ranging from 10 to 62 cm (Figure 4) and located over a substrate ranging from silt to cobble (Figure 8).

Juvenile Chinook Movement

Of the 354 age 0 chinook salmon fin clipped on the North Fork, only 21% were recovered from within the marking sites after temperatures dropped below 4 C (Table 4). Three percent of the marked chinook that left the marking sites were found within 20 m directly below the sites in which they were marked while the other 76% were never located. Thus, it appears that the majority of the chinook left the drainage possibly because suitable winter habitat was not located.

The side channel located along the sediment trap had the least amount

of marked chinook moving out of the site (45%) while the middle and lower sites of the sediment trap had 100% emigration (Table 4). Undercut banks with Carex extending below the surface of the water was absent from the middle and lower sediment trap sites.

Movement of chinook was not limited to fish of a single size category; rather, fish of all lengths moved out of the marking sites (Figure 2). More fish of lengths 63 to 73 mm moved out of the site than did fish of other lengths. This can be partly explained because originally, in October, more fish were located and marked ranging in lengths between 63 to 73 mm thus, we would expect more of these fish to move out because more of them were originally present within the site.

Stream Bed Alteration

When comparing altered areas with unaltered areas, a higher density of age 0 chinook were found utilizing interstitial spaces in the altered subsrate (Table 6). A higher density of salmon was found utilizing cobble placed under the bank than were utilizing cobble placed in the exposed benthic area. Also, more salmon were found utilizing the altered glide habitat (434 fish per 100 m^2) than the altered riffle habitat (375 fish per 100 m^2) in November (Table 5 & 6). Thus, our results strongly suggest that juvenile chinook select interstitial spaces in the substrate, if available, over undercut banks with Carex extending beneath the water surface. It further suggests that stream sediment has a detrimental effect on the amount of winter habitat available for overwintering juvenile chinook salmon.

Spawning Habitat

Adult chinook salmon consistently selected transitions between pool (glide) - riffle areas for redd construction. These spawning areas had a consistent water depth, velocity and substrate (Figures 9, 10, & 13).

Depths ranged from 16 to 41 cm (Figure 9) while velocities ranged from 11 to 52 cm/s (Figure 10). Selected substrate ranged predominantly between 50 and 230 mm in diameter (Figure 13) with 25 to 75 percent of their surface covered by fine sediment (Figure 14).

The mean area of the redds constructed by the females was 1.3 m^2 (Figure 11) which were located between 2 and 22 m from cover (predominantly undercut banks) (Figure 12).

Sediment core samples taken before and immediately following spawning indicate that pore size and permeability within the substrate increased after spawning (Table 7, Figures 15-18). An increase in average geometric mean from 21 to 32 was noted after spawning (Table 7). Ranges in geometric means were similar, ranging from 5 to 96 in August and 5 to 98 in September (Figure 15). An increase in permeability was also noted, with decreases in mean sorting coefficients from 5.3 in August to 4.6 in September (Table 7). A wide range of sorting coefficients occurred in August (2.0 to 10.0) (Figure 16). In September sorting coefficients ranged from 3.0 to 9.0 with the majority less than 5.0 (Figure 16).

An increase in the mean fredle index from 4 in August to 6 in September further indicates an increase in pore size and permeability within the substrate (Table 7). In August the majority of the fredle numbers were greater than 1.0 while after spawning the majority was greater than 2.0 (Figure 17). Thus, we would expect an increase in embryo survival. Presently, relationships between fredle numbers and chinook embryo survival have not been determined.

Using the embryo survival equation derived by Tappel, a mean increase from 53% to 69% in embryo survival could be expected (Table 7). The equation calculates an index of fine sediment less than 0.85 and 9.5 mm, measured in terms of percent survival. Thus, embryo survival values are

indirectly proportional to the amount of fine sediment present. In August, before spawning, we see that more fine sediment must have been present than was present after spawning (Figure 18). This is because the majority of percent survival values were less than 70% in August while in September, after spawning, the majority of values were greater than 70%.

ACKNOWLEDGMENT

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TABLE 1. Physical characteristics of the sites selected for winter habitat alteration, September 1985.

Habitat	Length (m)	Mean width (m)	Mean depth ± SD (cm)	Mean velocity ± SD (cm/s)	Total benthic area (m^2)	Benthic area under banks (m^2)	Exposed benthic area[a] (m^2)
Glide	31.0	4.1	28 ± 10	16 ± 6	128.5	9.5	119
Riffle	22.6	4.9	41 ± 12	34 ± 8	111.5	7.5	104

[a] The difference between total benthic area and benthic area under banks.

TABLE 2. Numbers, biomass (grams of fish tissue per square meter) and densities (fish per 100 m^2) of age 0 chinook salmon collected on the upper site above the Red River Corrals in 1985. Numbers and densities of chinook collected in 1984 on the same site are given for comparison.

Month	Number		Density		Biomass	
	1984	1985	1984	1985	1984	1985
August	291	365	63	79	----	0.8
October	---	116	--	25	----	0.7
November	69	42	15	9	----	0.3

TABLE 3. Mean ± SDs of microhabitat measurements for age 0 chinook salmon from July through November 1985 Red River.

Month	Sample size	Total depth (cm)	Focal point elevation (cm)	Relative depth	Focal point velocity (cm/s)	Distance to cover (cm)	Substrate composition
July	94	44 ± 22	5 ± 3	.86 ± .07	10 ± 5	88 ± 44	4.4 ± 0.9
August	101	45 ± 11	6 ± 3	.85 ± .08	12 ± 5	106 ± 38	5.0 ± 1.0
September	86	49 ± 18	8 ± 4	.81 ± .10	13 ± 8	172 ± 58	4.9 ± 0.8
October	68	62 ± 30	24 ± 21	.65 ± .35	15 ± 5	------	4.3 ± 1.0
November	52	31 ± 12	22 ± 11	.32 ± .16	4 ± 2	------	4.7 ± 0.9

TABLE 4. Numbers and densities (fish per 100 m^2) of age 0 chinook salmon marked on 10-18 October 1985 and recaptured, in parenthesis, on 4-15 November 1985 in ten sites.

Date		Bridge Creek sites			Red River Corral sites			Sediment Trap sites			
		upper	middle	lower	upper	middle	lower	upper	middle	lower	side channel
10-18 Oct.	Number	35	21	25	24	58	65	23	18	9	76
	Density	22	18	16	12	23	25	5	4	2	40
4-15 Nov.	Number	12(5)	13(7)	15(3)	11(3)	20(7)	27(6)	4(1)	0(0)	0(0)	46(42)
	Density	8	11	10	6	8	10	1	0	0	24

a Initially, 12 October, 23 age 0 chinook salmon were marked. During a brief warming period, 18 October, an additional 35 age 0 chinook salmon were marked.

b Initially, 13 October, 34 age 0 chinook salmon were marked. During a brief warming period, 18 October, an additional 31 age 0 chinook salmon were marked.

TABLE 5. Population estimates ± 95% confidence intervals and densities of age 0 chinook salmon and other salmonids in Red River before and after alteration by addition of cobble on 23 September 1985.

Habitat	Date	Method	Fish species							Total No. Salmonids	Density per 100 m^2
			age 0 chinook	I+ chinook	rainbow	cutthroat	brook	bull	whitefish		
Glide	4 April	Shock	4±0	0	0	0	0	0	0	4	3
	21 Sept.	Snorkel	85±53	3±0	0	0	0	0	22±16	110	86
	23 Sept.	----------	----------	Sites altered by the addition of cobble						----------	----------
	10 Oct.	Shock	53±4	0	0	0	2±0	5±1	8±0	68	53
	8 Nov.	Shock	40±2	0	0	0	1±0	1±0	1±0	43	33
Riffle	4 April	Shock	0	0	0	0	0	0	0	0	0
	21 Sept.	Snorkel	41±43	0	0	0	1±1	0	8±11	50	45
	23 Sept.	----------	----------	Sites altered by the addition of cobble						----------	----------
	10 Oct.	Shock	28±2	0	0	0	2±0	0	2±0	32	25
	8 Nov.	Shock	25±1	0	0	2±0	0	0	0	27	24

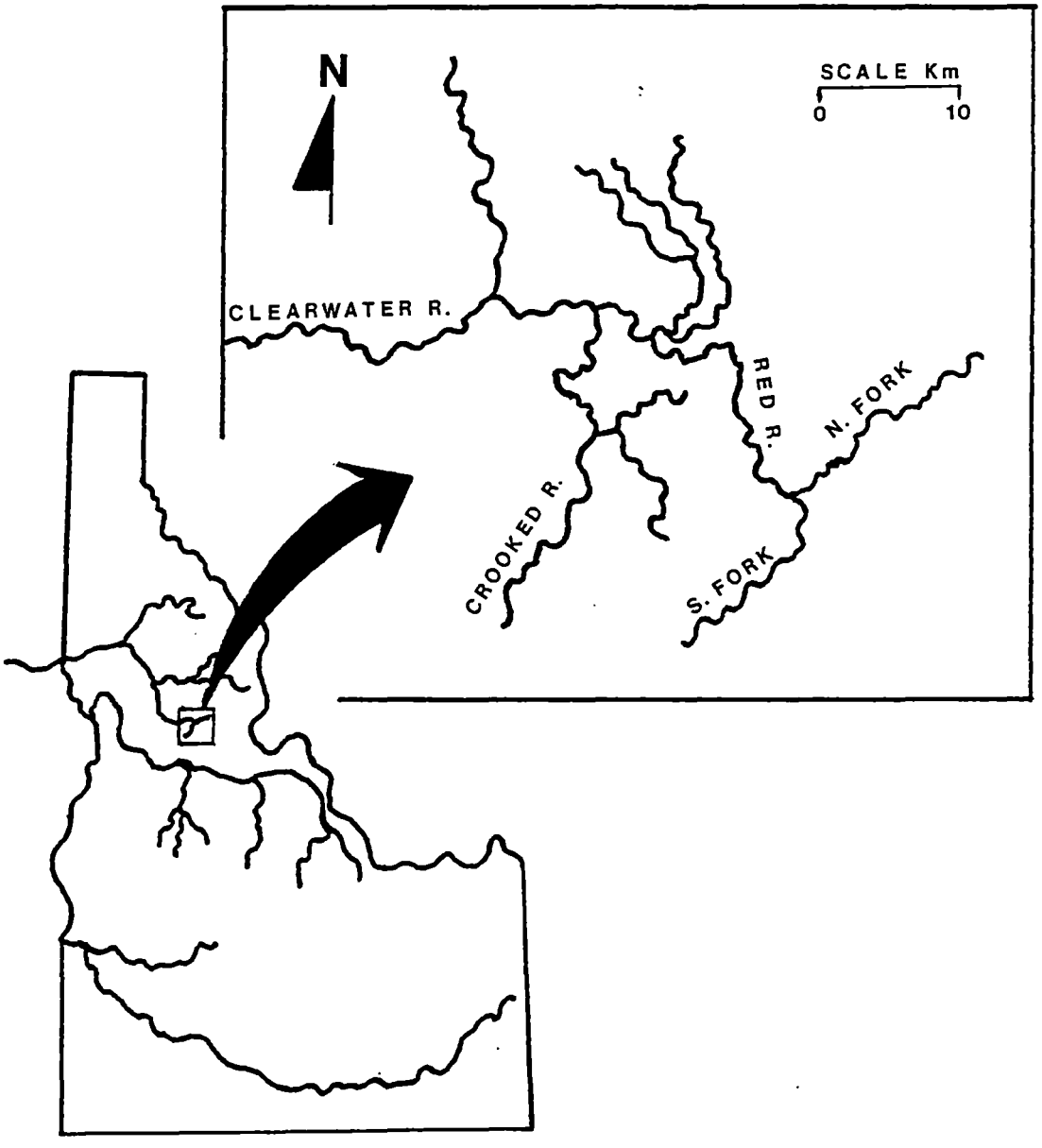
TABLE 6. Numbers and densities per 100 m^2 of substrate, in parenthesis, of age 0 chinook salmon found within altered and unaltered areas of winter habitat sites, 1985.

Habitat	Date	Exposed benthic substrate		Underbank benthic substrate	
		altered	unaltered	altered	unaltered
Glide	10 Oct.	12(235)	0(0)	33(1031)	8(127)
	8 Nov.	16(314)	0(0)	20(625)	4(63)
Riffle	10 Oct.	10(238)	0(0)	18(818)	0(0)
	8 Nov.	8(190)	0(0)	16(727)	1(19)

TABLE 7. Mean substrate quality indices ± standard deviation calculated for chinook salmon spawning gravels on Red River, 1985. Periods of 6-13 August, 19-21 September, and 17-21 March indicate pre-spawning, immediately following spawning, and during hatching of the eggs, respectively.

Date	Sample size	Percent sample less than 0.85 ($S_{.85}$)	Percent sample less than 9.5 ($S_{9.5}$)	Geometric mean (dg)	Sorting coefficient (So)	Fredle index (f)	Percent survival[a] (%s)
6-13 Aug.	39	11 ± 5	43 ± 9	21 ± 17	5.3 ± 1.7	4 ± 3	53 ± 24
19-21 Sept.	15	7 ± 3	39 ± 13	32 ± 34	4.6 ± 1.8	6 ± 4	69 ± 23
17-21 March							

[a] Calculated by using the equation: $93.4 - 0.171 (S_{9.5}) (S_{.85}) + 3.87 (S_{.85})$ (Tappel and Bjornn 1983).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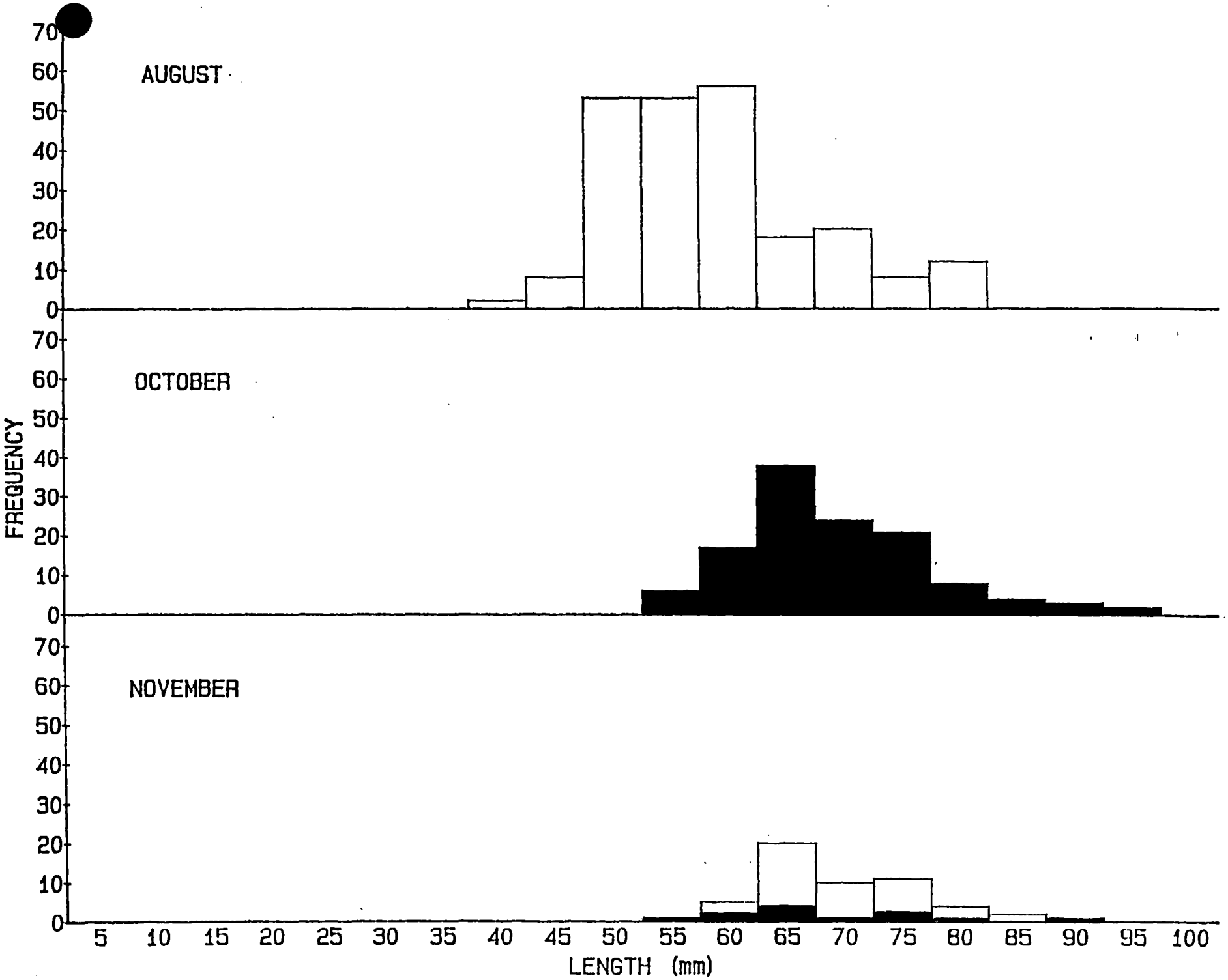
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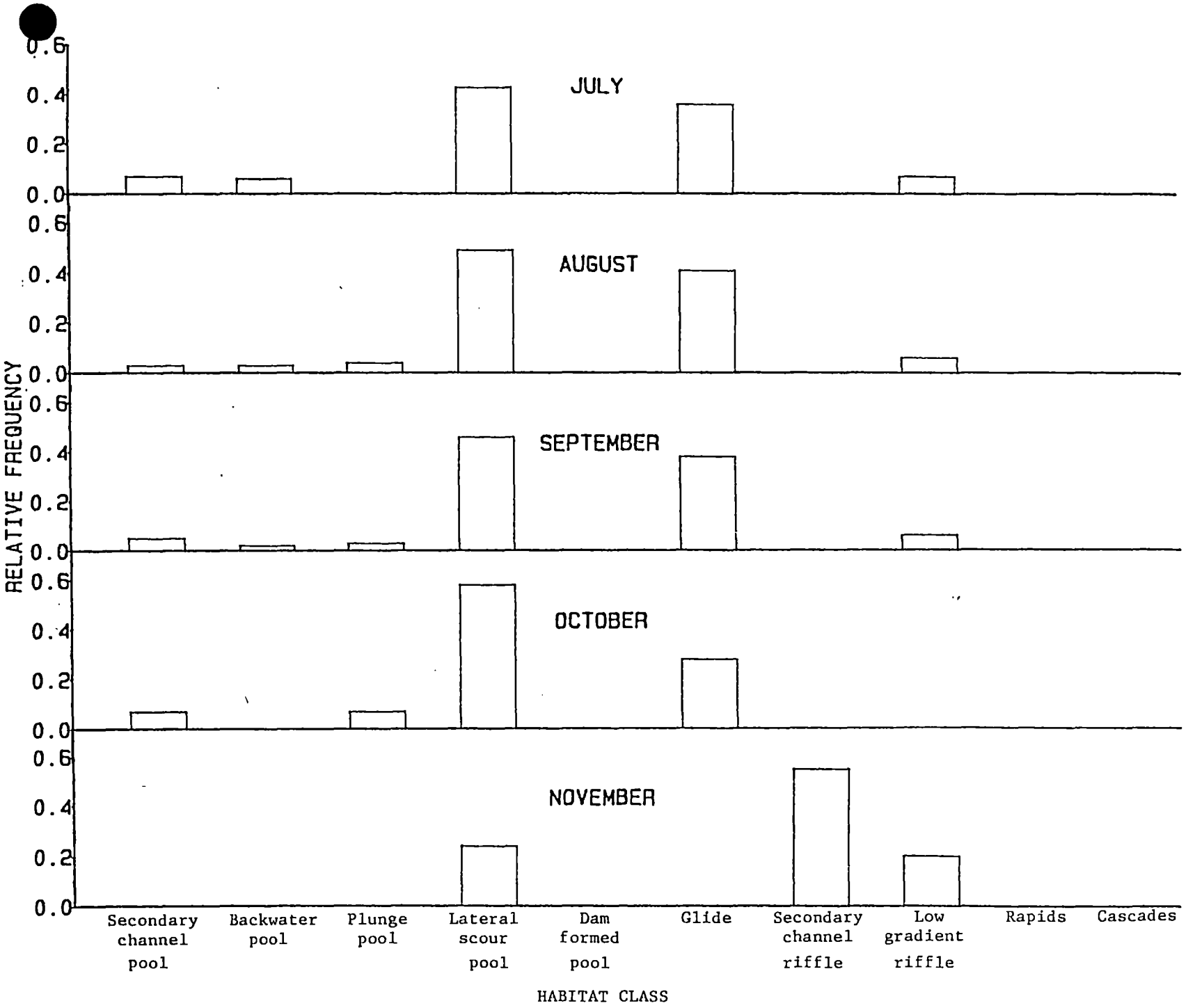
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SEPTEMBER
OCTOBER
NOVEMBER
RELATIVE FREQUENCY
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0.2
0.4
0.6
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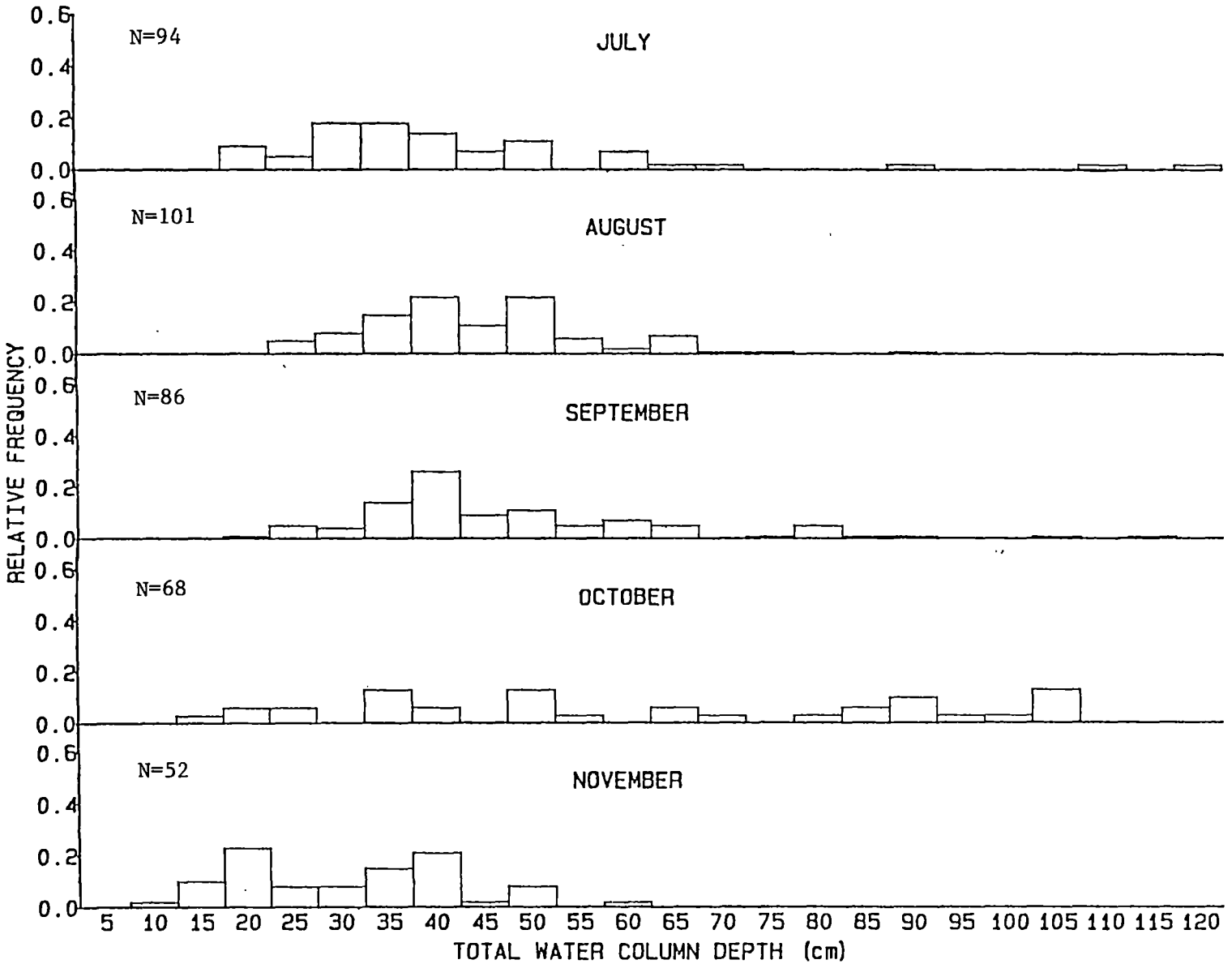
Plunge pool
Lateral scour pool
Dam formed pool
Glide
Secondary channel riffle
Low gradient riffle
Rapids
Cascades
HABITAT CLASS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RELATIVE FREQUENCY
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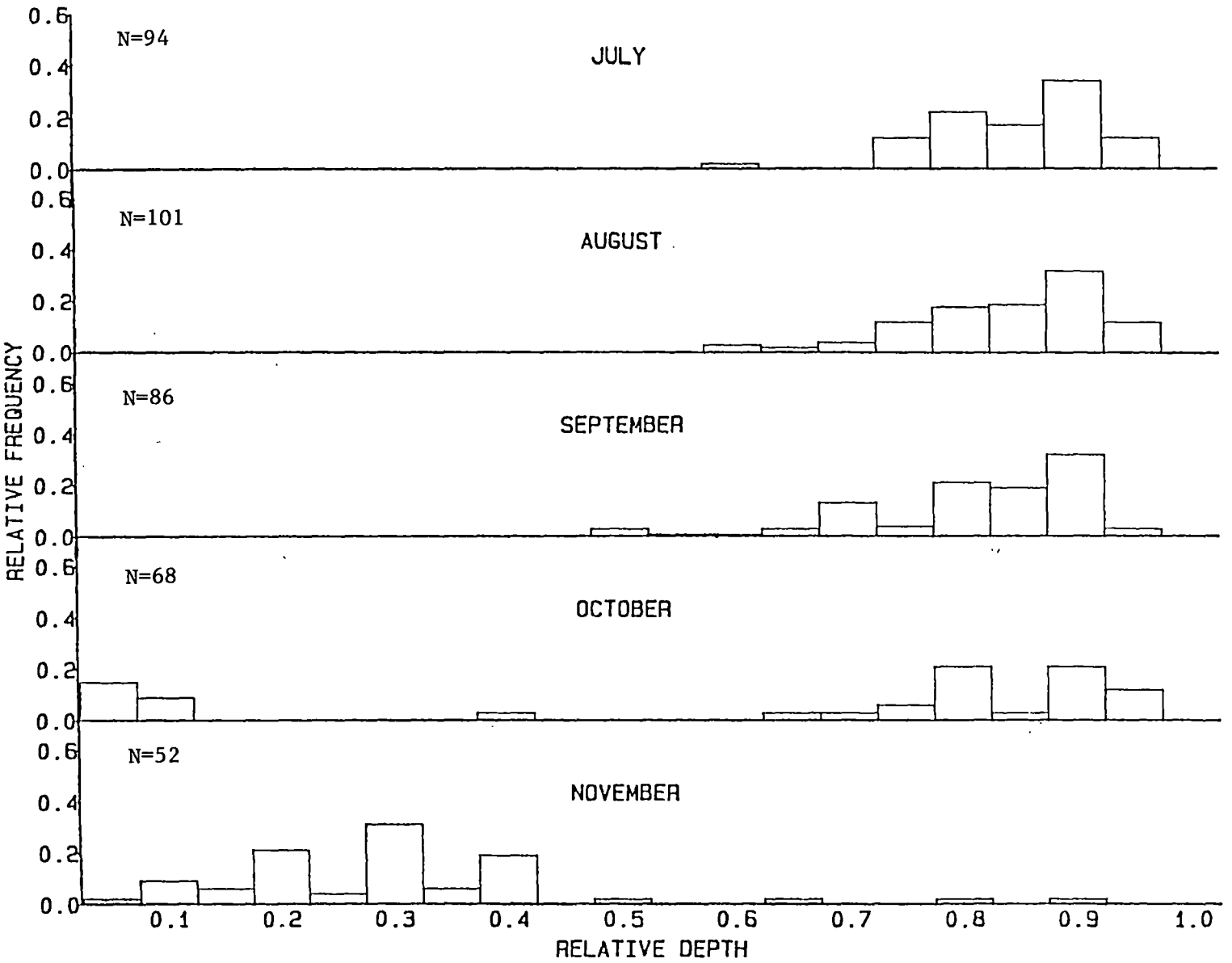
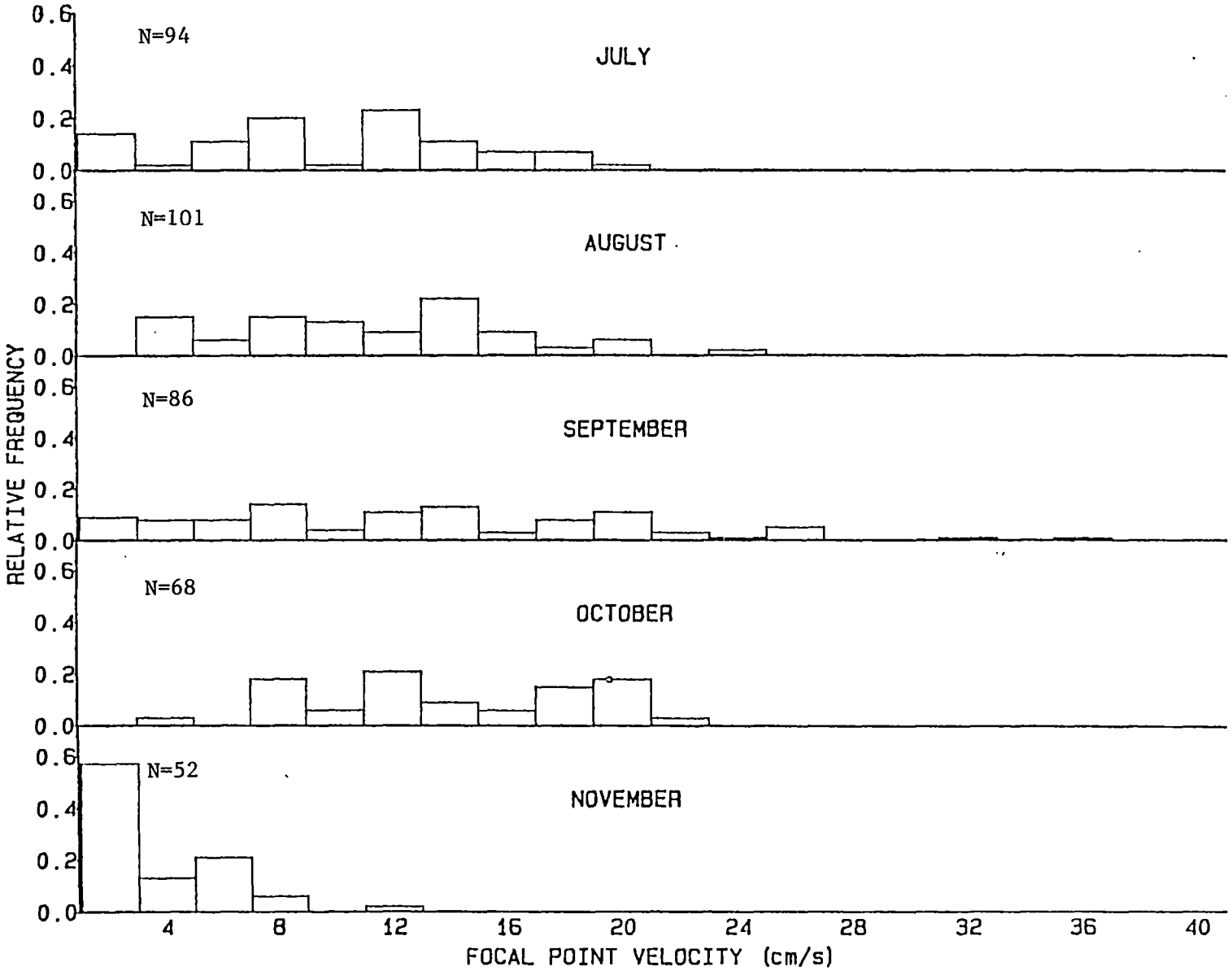
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120
TOTAL WATER COLUMN DEPTH (cm)


N=94
JULY
N=101
AUGUST
N=86
SEPTEMBER
N=68
OCTOBER
N=52
NOVEMBER
RELATIVE FREQUENCY
0.0
0.2
0.4
0.6
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
RELATIVE DEPTH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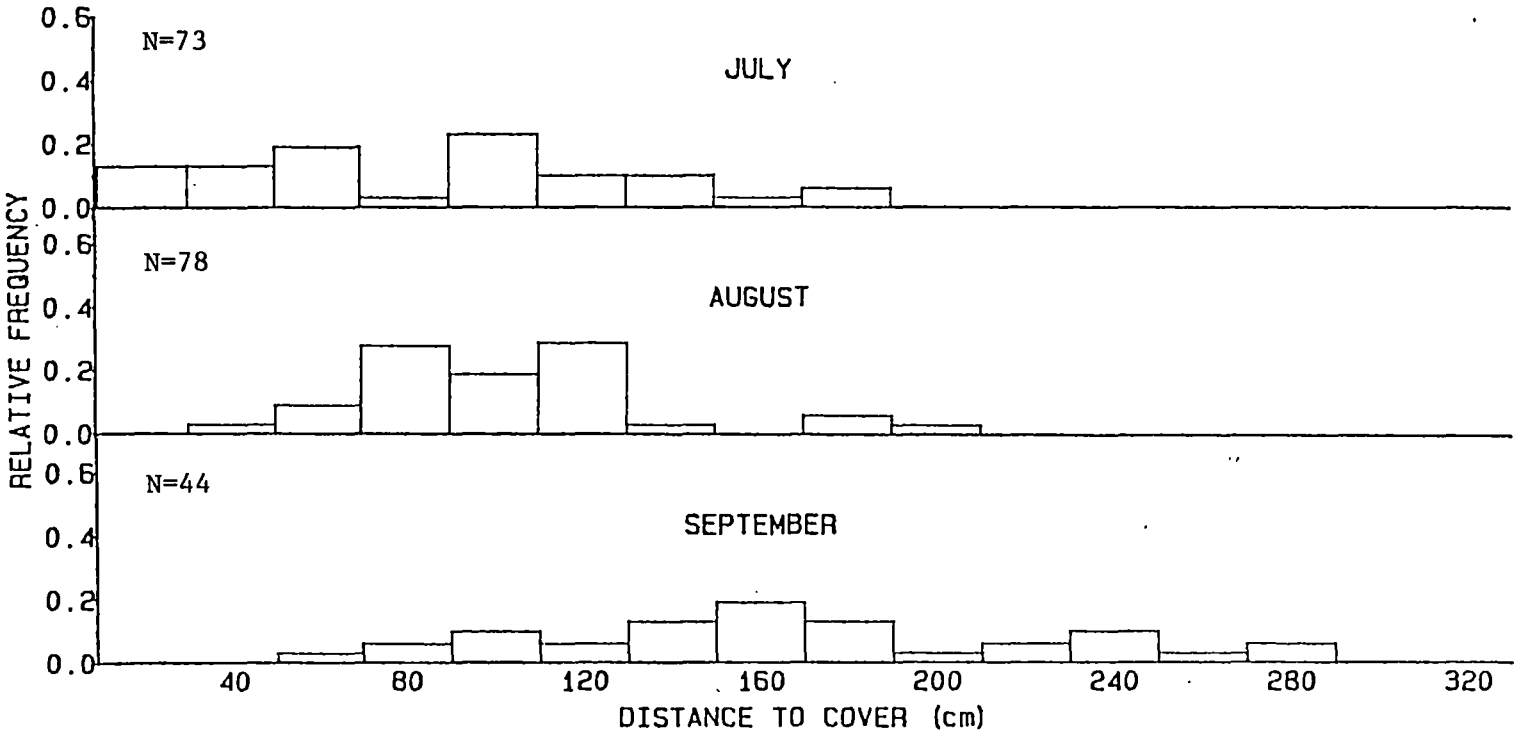
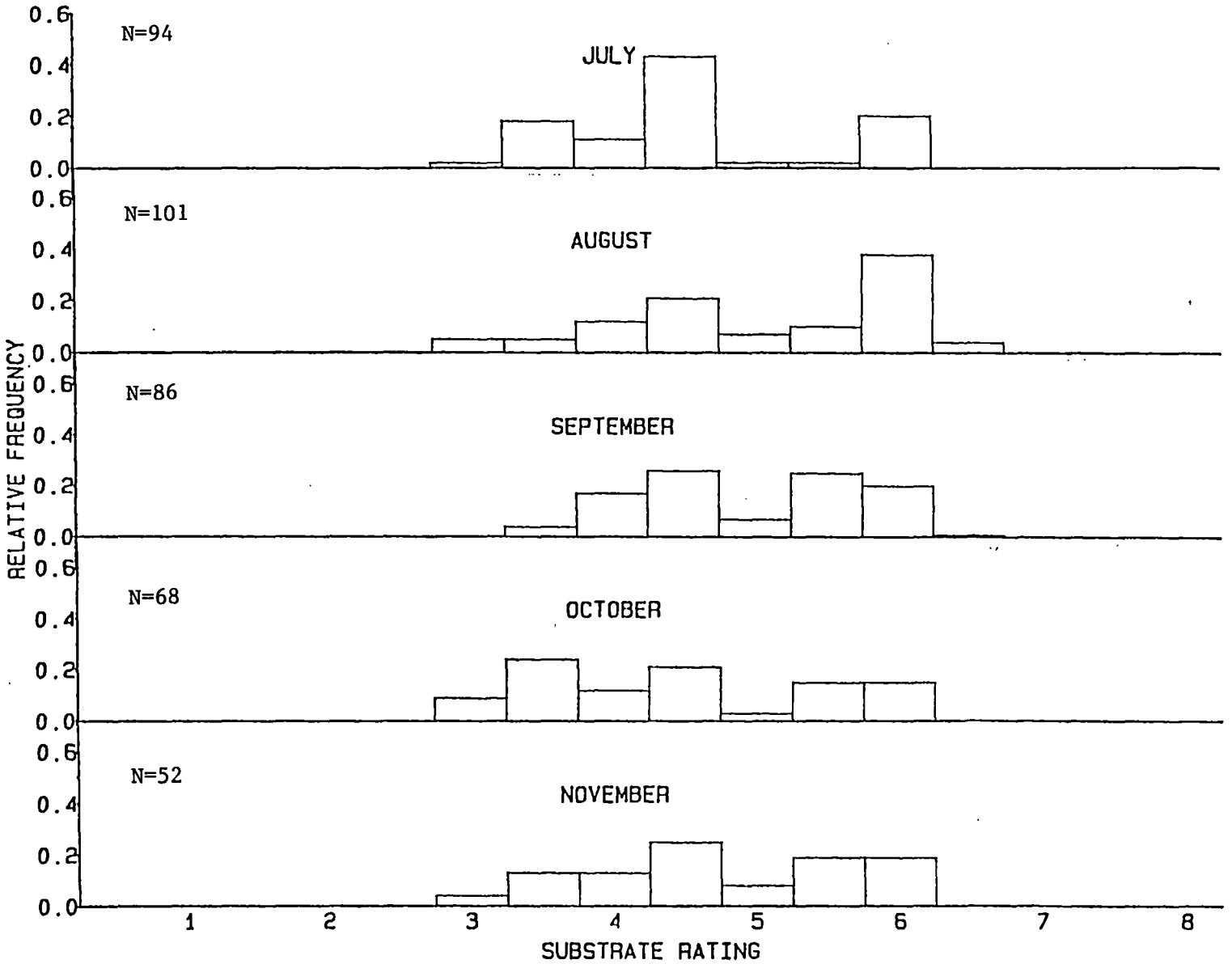
JULY
N=101
AUGUST
N=86
SEPTEMBER
N=68
OCTOBER
N=52
NOVEMBER
0.6
0.4
0.2
0.0
RELATIVE FREQUENCY
4
8
12
16
20
24
28
32
36
40
FOCAL POINT VELOCITY (cm/s)


N=73
JULY
N=78
AUGUST
N=44
SEPTEMBER
RELATIVE FREQUENCY
0.0
0.2
0.4
0.6
40
80
120
160
200
240
280
320
DISTANCE TO COVER (cm)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JULY
N=101
AUGUST
N=86
SEPTEMBER
N=68
OCTOBER
N=52
NOVEMBER
0.6
0.4
0.2
0.0
RELATIVE FREQUENCY
1
2
3
4
5
6
7
8
SUBSTRATE RATING

FIGURE 9.

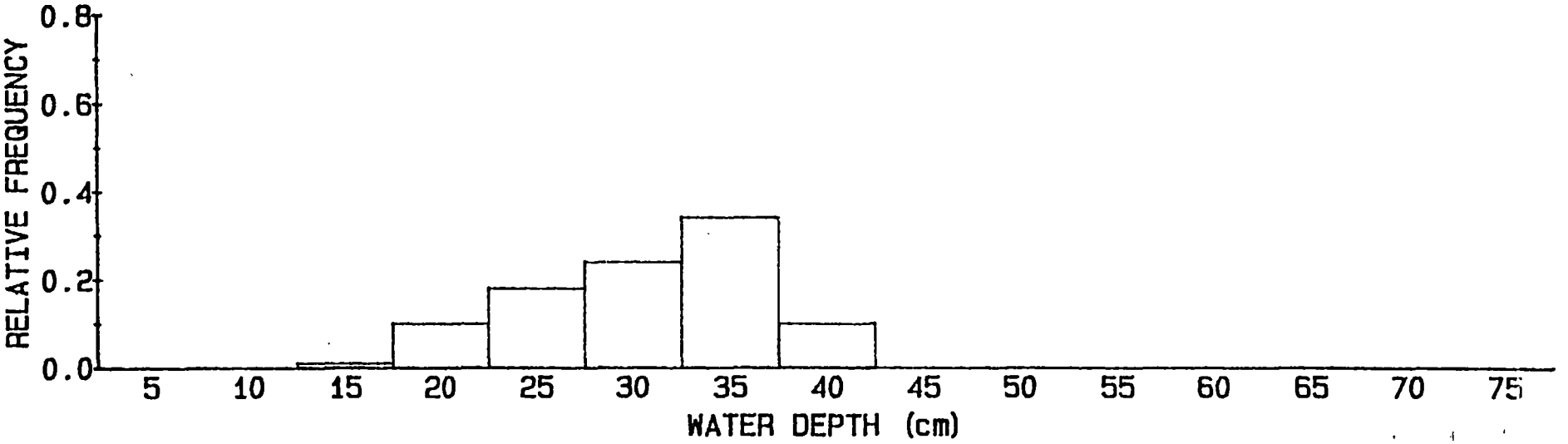


FIGURE 10.

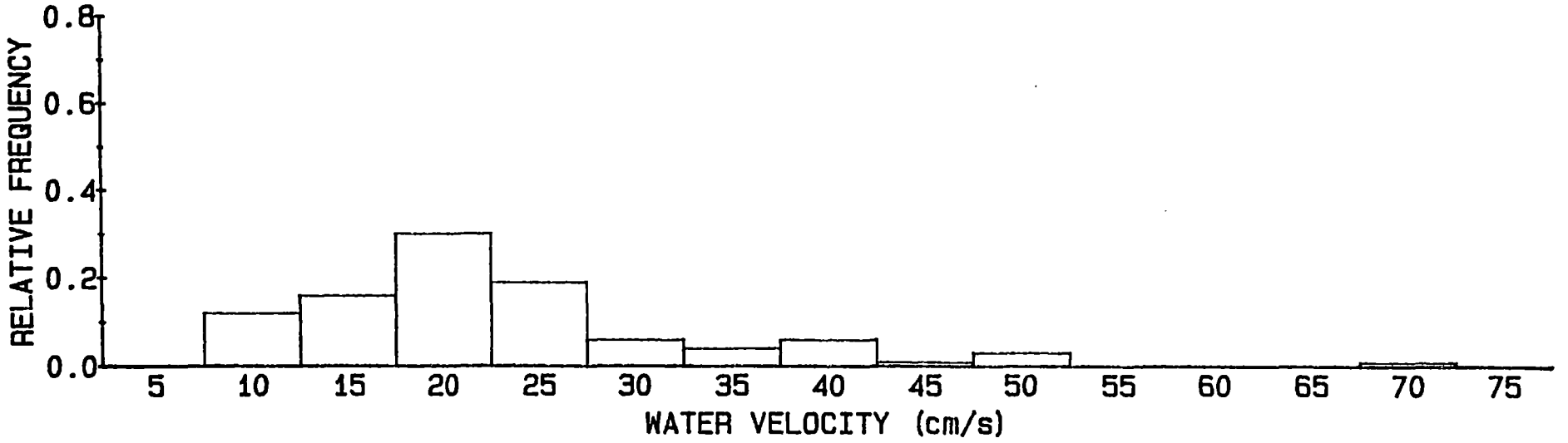


FIGURE 11.

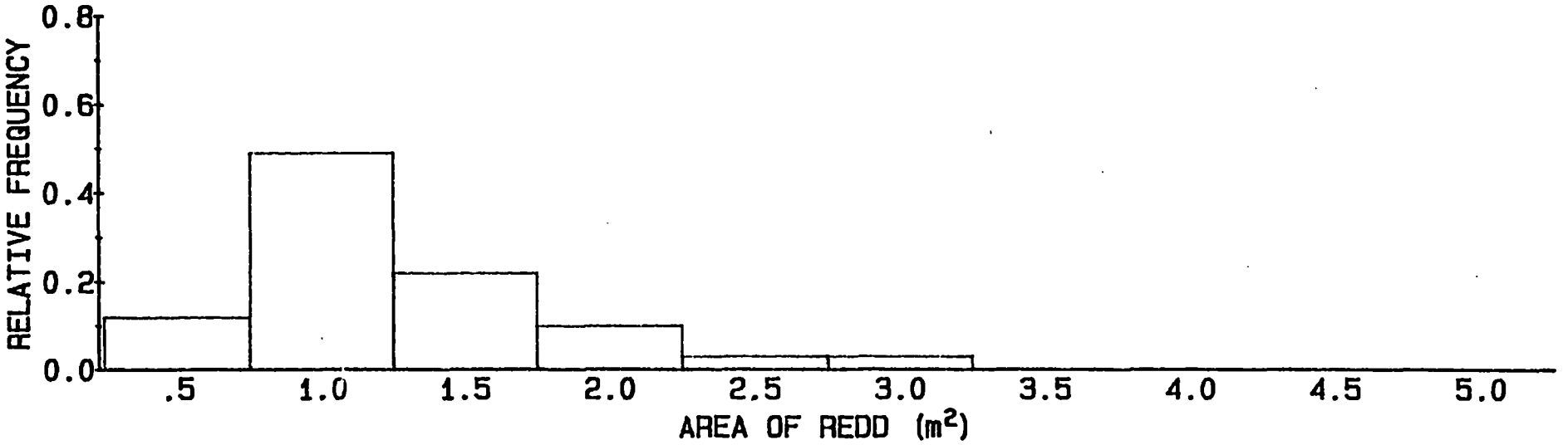


FIGURE 12.

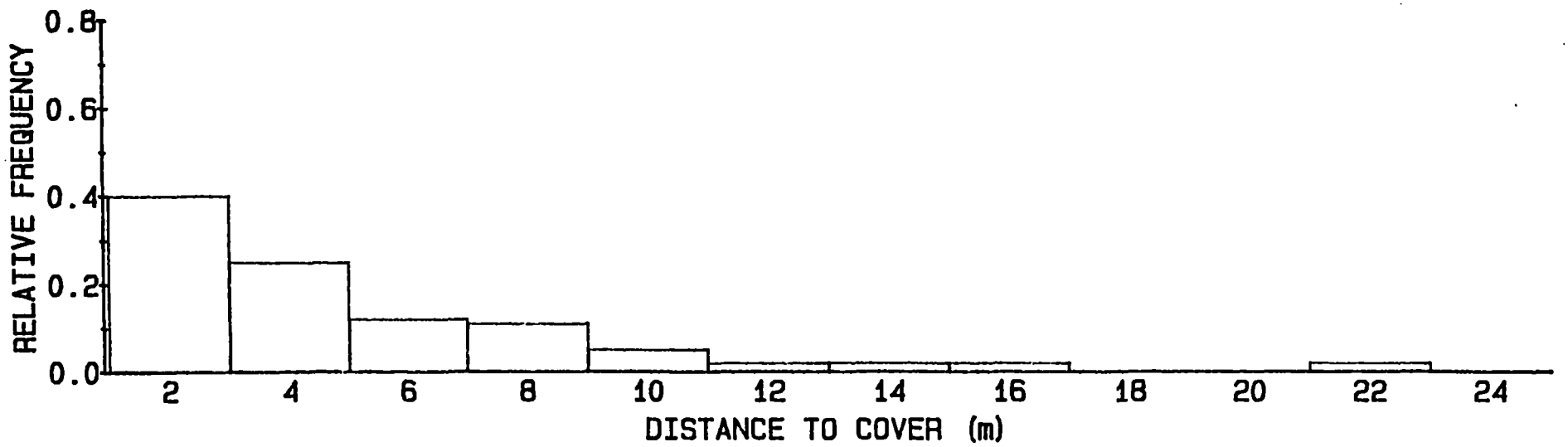


FIGURE 13.

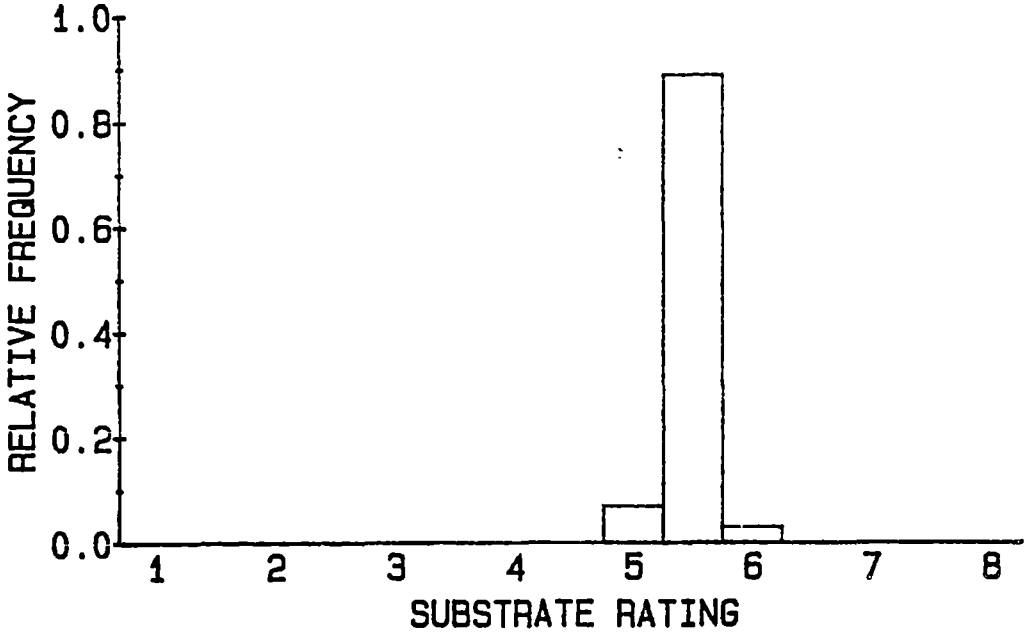
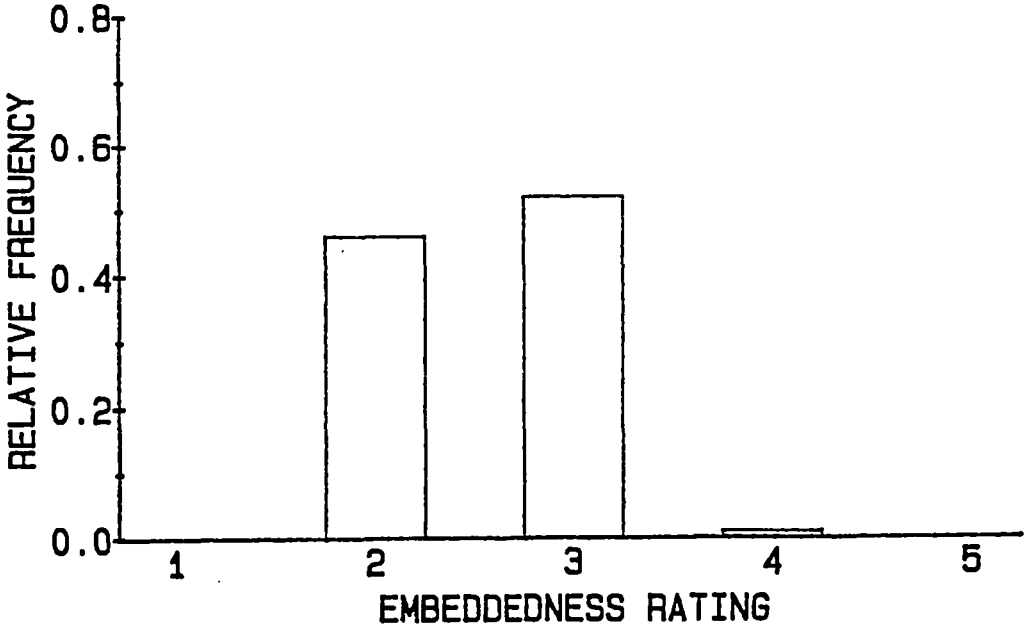
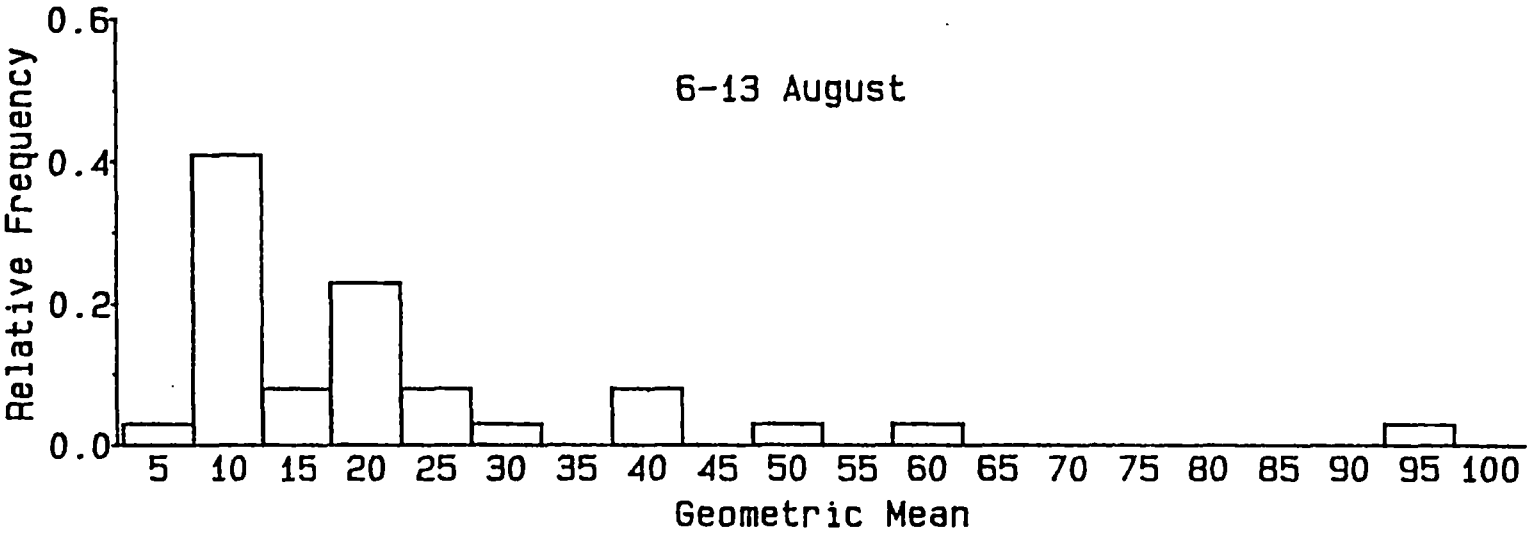
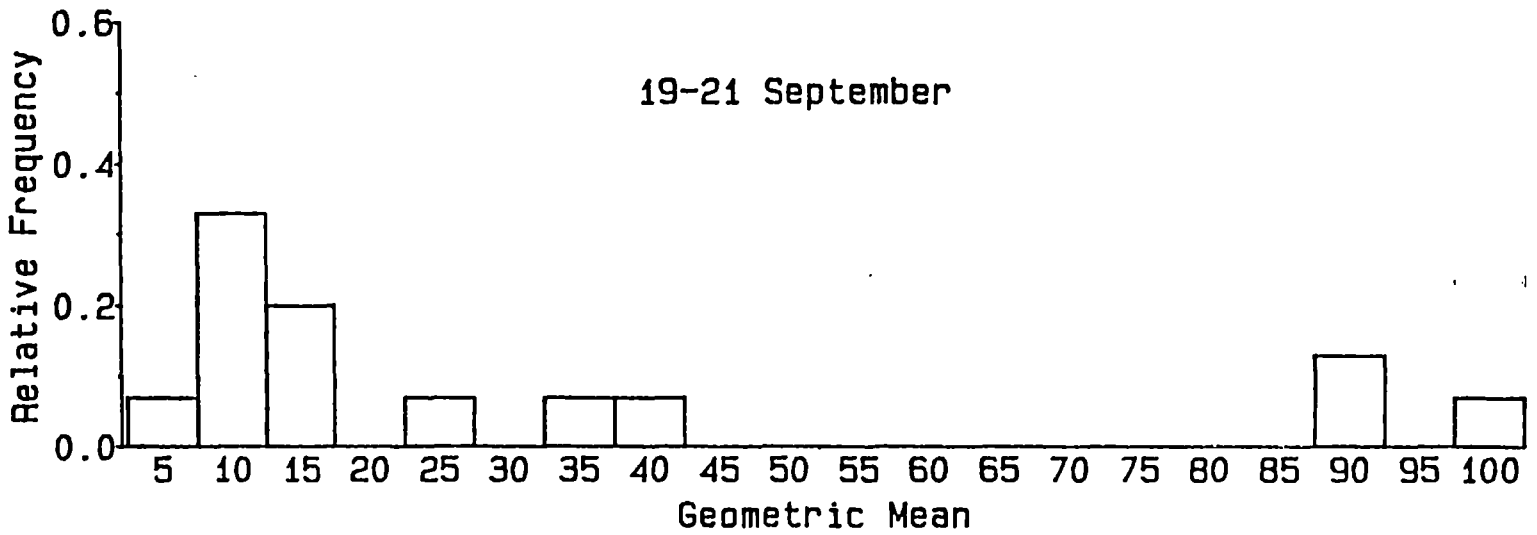
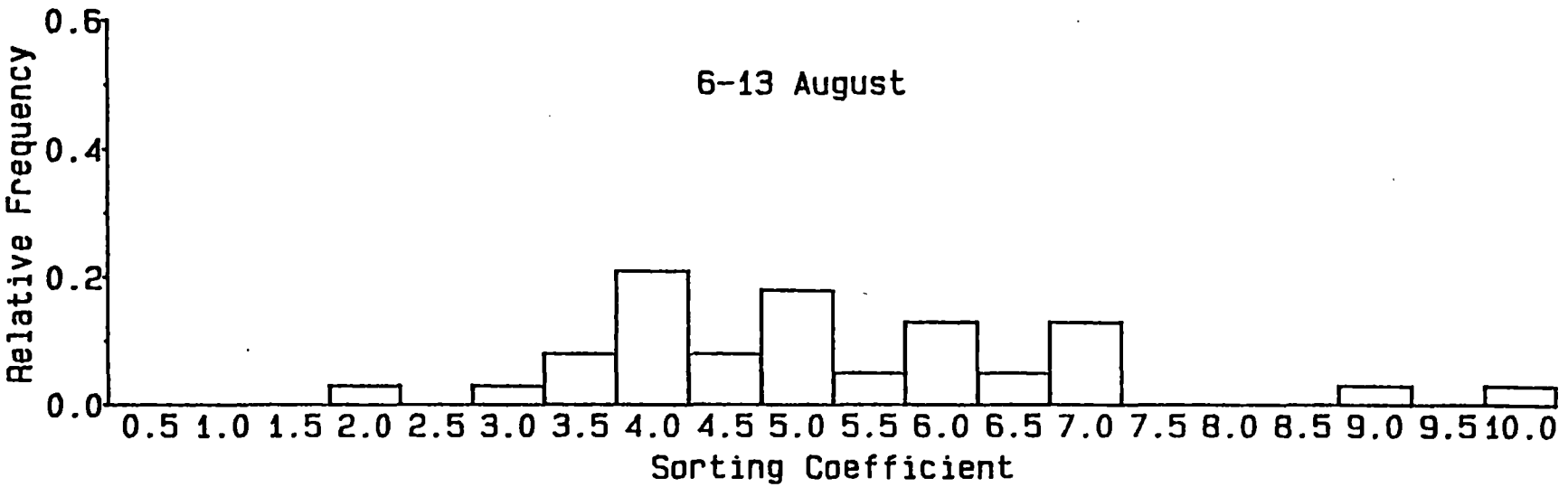


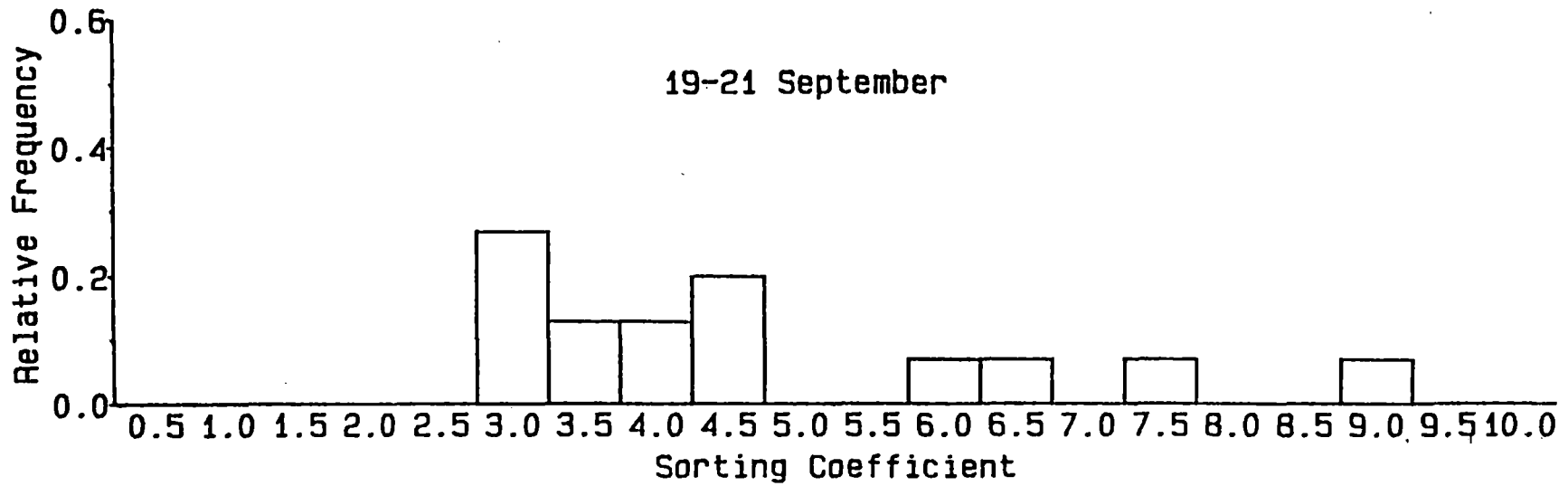
FIGURE 14.

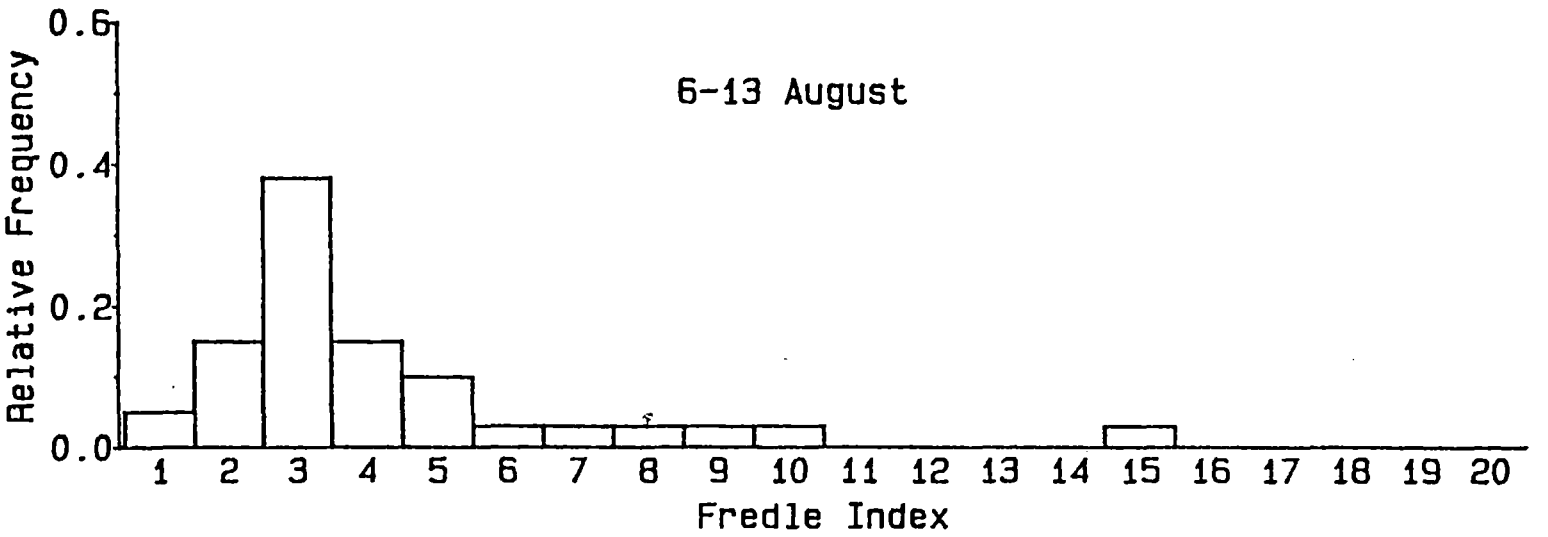


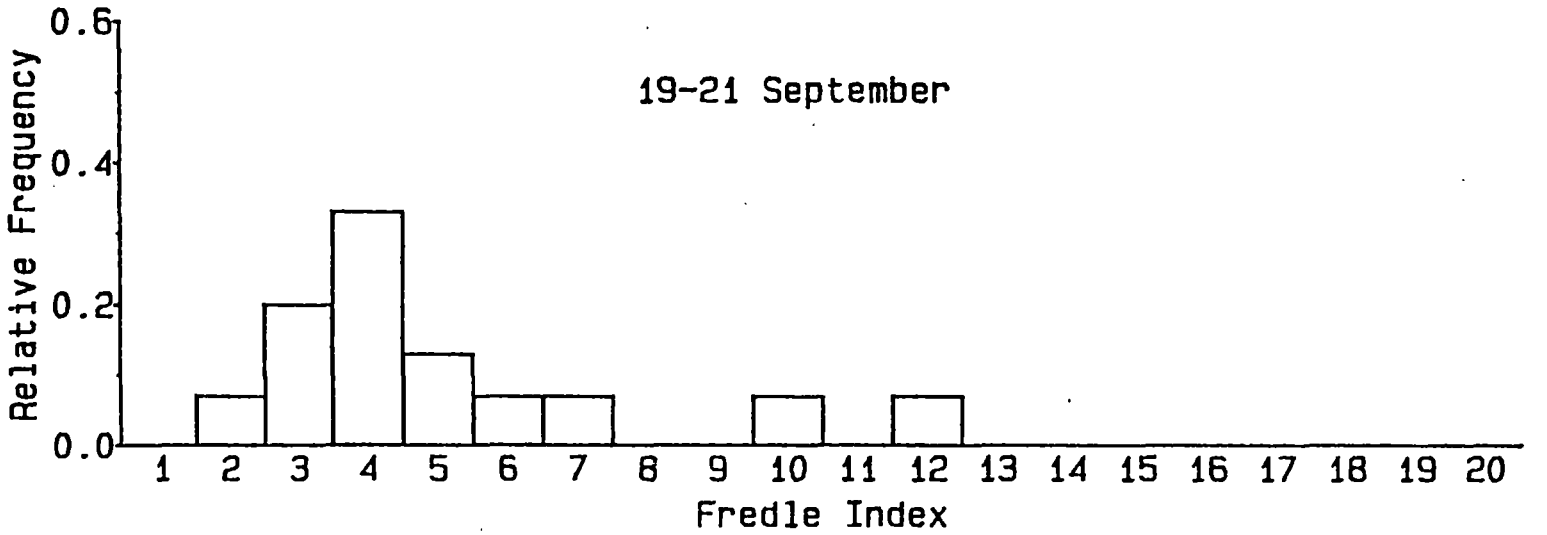

6-13 August
Relative Frequency
0.6
0.4
0.2
0.0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Geometric Mean

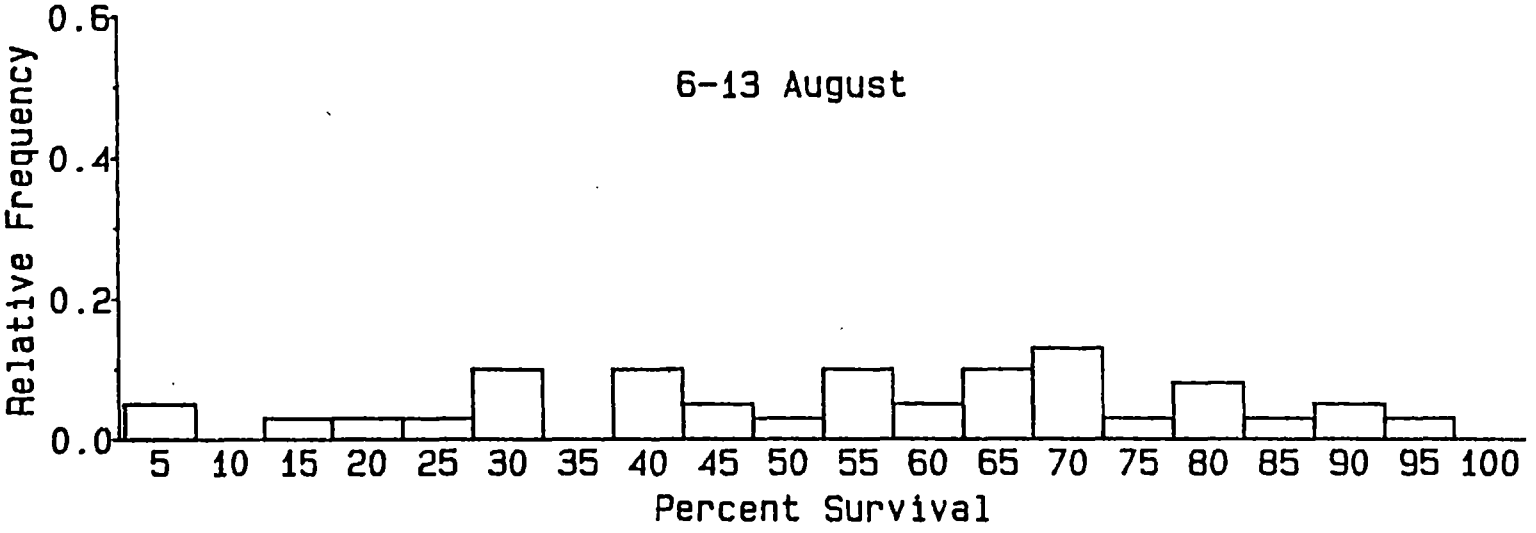

19-21 September
Relative Frequency
0.6
0.4
0.2
0.0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Geometric Mean

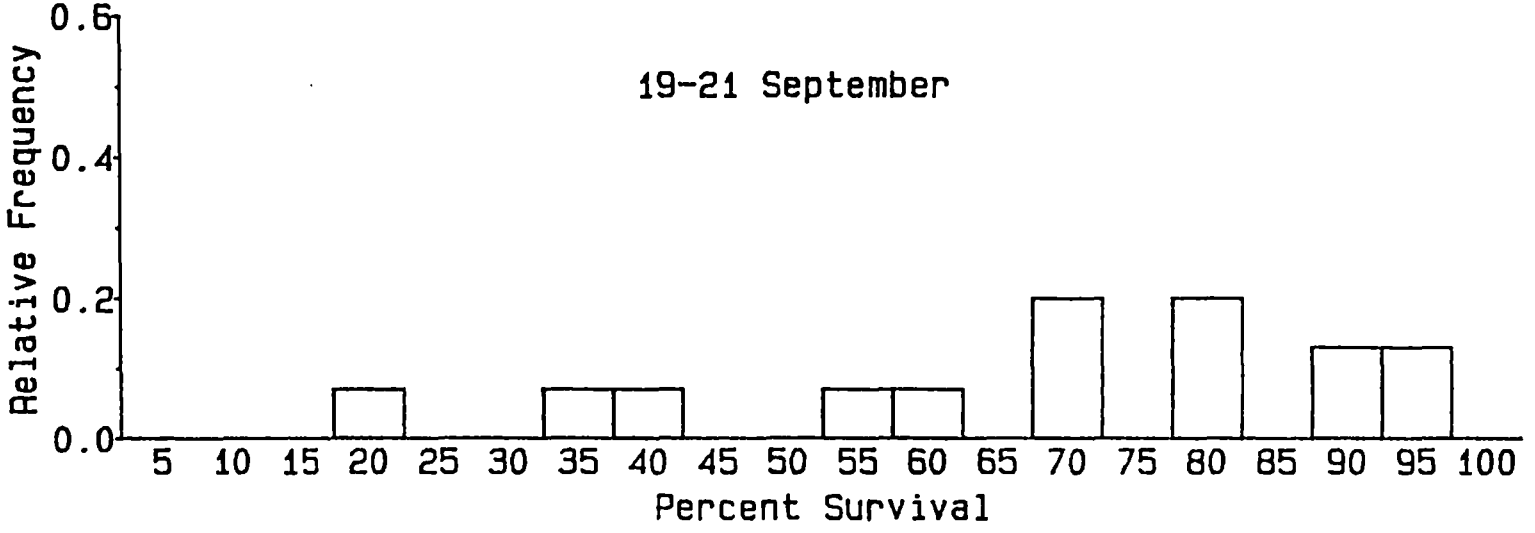

6-13 August
Relative Frequency
0.6
0.4
0.2
0.0
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0
Sorting Coefficient


19-21 September
Relative Frequency
0.6
0.4
0.2
0.0
0.5 1.0 1.5 2.0 2.5 3.0 3.5 4.0 4.5 5.0 5.5 6.0 6.5 7.0 7.5 8.0 8.5 9.0 9.5 10.0
Sorting Coefficient


6-13 August
Relative Frequency
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Fredle Index


19-21 September
Relative Frequency
0.6
0.4
0.2
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Fredle Index


6-13 August
Relative Frequency
0.6
0.4
0.2
0.0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Percent Survival


19-21 September
Relative Frequency
0.6
0.4
0.2
0.0
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100
Percent Survival

APPENDIX 1--HABITAT CLASSES

Rating criteria and codes for stream habitat classes.

Code	Habitat	Habitat description
1	Secondary Channel Pool	Pools that remain within the bankful margins of the stream after freshets and usually associated with gravel bars.
2	Backwater Pool	Pools that are found along channel margins and are caused by eddies behind large obstructions.
3	Plunge Pool	Pools that occur where the stream passes over a complete or nearly complete channel obstruction and drops vertically into the streambed below, scouring out a depression.
4	Lateral Scour Pool	Pools formed where the flow is directed to one side of the stream by a partial channel obstruction often forming undercut banks.
5	Dam Formed Pool	Pools formed by water impounded upstream from a complete or nearly complete channel blockage.
6	Glide	Glides are characterized by moderately shallow water with an even flow that lack pronounced turbulence.
7	Secondary Channel Riffle	A riffle that is not part of the main channel.
8	Low Gradient Riffle	Shallow stream reach with moderate current velocity (20-50 cm/s) and moderate turbulence. Upper gradient limit of 4%.
9	Rapids	Rapids possess a gradient greater than 4% with swiftly flowing water (50 cm/s) having considerable turbulence.
10	Cascades	Cascades are the steepest, consisting of a series of small steps of alternating small waterfalls and shallow pools.

APPENDIX 2--SUBSTRATE CODES

Substrate codes for stream channel materials by particle size.

Code	Particle diameter size	Sediment classification
1		Plant detritus
2	.004 or less	Clay
3	.005 to .82	Silt
4	.83 to 4.71	Sand
5	4.81 to 76.0	Gravel
6	76.1 to 304.0	Cobble
7	305.0 or more	Boulder
8		Bedrock